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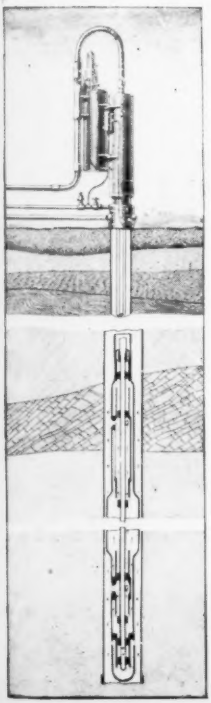

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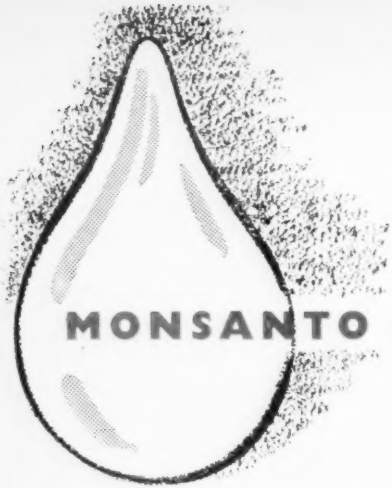

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FOURTH EMPIRE MINING AND METALLURGICAL CONGRESS. GREAT BRITAIN—1949

By T. DEWHURST (Fellow and Past-President)

THE First Empire Mining and Metallurgical Congress was convened by seven technical bodies, including the Institution of Petroleum Technologists, and was held at Wembley in connexion with the great British Empire Exhibition of 1924.

The Second Congress was held in Canada in 1927, and the Third in South Africa in 1930. It was hoped that the Fourth Congress would be held in Australia in 1933, but this proved to be impracticable owing to the very adverse economic conditions of the early thirties. Indeed, it proved to be impossible to hold the Congress again before the Second World War. After the war, the Empire Council of Mining and Metallurgical Institutions, consisting of representatives of some eleven constituent bodies, including the Institute of Petroleum, decided that the Fourth Congress should be held in Great Britain in 1949.

The Prime Minister was the Honorary President of the Congress, the President being Sir Henry T. Tizard, chairman of the Advisory Council on Scientific Policy. The Treasurer was Sir Clive L. Baillieu, Chairman of the Empire Council of Mining and Metallurgical Institutions. The Honorary Vice-Presidents included the Cabinet Ministers concerned with science, mining, the Dominions and Colonies, and also the Prime Ministers of all the Dominions.

The Congress was well attended by

delegates and members from all parts of the Commonwealth and Empire, and also from the U.S.A. Members also attended from some eight countries of Europe, and from Egypt, Iraq, Portuguese West Africa, and Chile.

The general programme was arranged in three stages. From July 9 to 12 the proceedings took place in London; the technical sessions were held in Oxford from July 12 to 17; and excursions were conducted from July 17 to 23.

The headquarters in London were at Grosvenor House, and the proceedings were opened by the President's reception to official delegates on the morning of Saturday, July 9. In the evening, delegates and members and their ladies were entertained at a Government reception at Lancaster House. The inaugural meeting was opened on Monday, July 11, by the Minister of Fuel and Power. Afterwards a very successful luncheon was held in the ballroom. In the afternoon a reception was given by the Parliamentary and Scientific Committee in the House of Commons, and at night a banquet was held in the Guildhall, the speakers including H.R.H. the Duke of Gloucester, the Minister of Fuel and Power, and the President of the Congress.

Visits were paid to the research laboratories of the General Electric Co. Ltd.; to the Underground Mining Machinery Exhibition at Earl's Court; to the laboratories of Hunting Aerosurveys Ltd. at Elstree; to the Fuel Research Station of the D.S.I.R., Greenwich; and to the Powell Duffryn Research Laboratories Ltd. at Battersea.

On Tuesday, July 12, delegates and members assembled in Oxford, the headquarters of the Congress being the Oxford Union Society. They were welcomed on behalf of the University by Sir Richard Livingstone, President of Corpus Christi College, and then settled down to the serious work of the Congress, the presentation and discussion of papers on numerous mining and metallurgical subjects. These were of special interest and importance, as there had been many developments to record and discuss since the last Congress in 1930. For example, there had been serious depletion of some easily accessible mineral deposits; mining operations had been carried out to increasingly greater depths and therefore under higher temperature conditions, and the effect of these conditions on the health of underground mine workers had become an important problem; new methods of locating mineral deposits had been developed and had greatly increased in importance; minerals, metals, and alloys that were of scientific interest only at the time of the last Congress had become part of the fabric of industry; and new uses for metals, and also new metallurgical processes for their recovery, had been developed.

Empire Mineral Resources

A series of important papers dealt with the mineral resources of the Dominions and Colonies. In the case of Australia, there were no major discoveries to record since the last Congress. There is a wide range of mineral production, but the most important deposits are the lead-zinc-silver ores of Broken Hill. Gold mining is still important, and the production of copper should increase in future. The goldfields and diamond mines of the Union of South Africa are too well known to require comment. However, there have been striking developments in regard to gold since the last Congress, as the Western Rand has been developed, and diamond drilling has indicated that many new gold mines will be opened up in the Orange Free State. Less well known to the general public are the large deposits of chromite, manganese, copper, antimony, asbestos, the platinum group of metals, etc. In the case of Canada, there has been an increase in the production of the major metals and minerals during the past decade, while others, notably

quicksilver, tungsten, fluorspar, tellurium, selenium, cadmium, bismuth, and tin, are now being produced.

A paper by Sir Lewis Fermor dealt with the mineral resources of Malaya, British North Borneo, Hong Kong, etc., and stressed the inadequacy of the British Government's provision for financial compensation for damage sustained during the war. Taxation is very heavy, and Malayan tin mining is perhaps the most highly taxed in the world. Reference was also made to the important Seria oilfield in Brunei, and to the phosphate deposits of Christmas Island.

Dr N. R. Junner described the principal mineral deposits of the British West African Colonies, which yield gold, tin ore, diamonds, manganese, iron ores, columbite, bauxite, chromite, etc. The mineral resources of the East African Colonies were described by Sir Edmund Teale. In regard to Tanganyika, he stressed the discovery by Dr Williamson in 1943 of the rich diamond field at Mwadui; also the recent discoveries in the Mpanda mines of complex ores yielding lead, silver, copper, and gold. Other minerals which occur in the Colony include tin, mica, iron, and platinum. Kenya has two important gold belts, and there are also deposits of kyanite and soda.

A paper was presented on the mineral resources of Southern Rhodesia. Although gold output has declined, the production of base metals has increased, the principal minerals being asbestos, chrome, and tin.

A paper by E. H. Beard dealt with the mineral resources of other Empire territories. In regard to Northern Rhodesia, he pointed out that since the previous Congress the famous copper belt had become one of the greatest copper and cobalt districts in the world, the cobalt being obtained mainly from the sulphide mineral carrollite. He also referred to several important advances in connexion with the well-known lead-zinc-vanadium mines at Broken Hill. In regard to British Guiana, the paper dealt with the important deposits of high-grade bauxite; diamonds and gold are also produced, while a variety of minerals of possible economic interest occur.

Dr D. N. Wadia contributed an extensive review of the mineral resources of India and Pakistan. He classified Indian minerals of world importance as being iron ore, mica, titanium ore, and thorianite; while there are available for export bauxite, corundum, magnesite, manganese ore, monazite, sillimanite and kyanite, silica, natural abrasives, and steatite. Recent discoveries include pitchblende and extremely fine emeralds.

Prospecting and Mining

Three interesting papers described the application of modern methods of prospecting to the search for new mineral deposits in South Africa, Australia, and Canada. In Canada large areas of potentially favourable ground have not yet been closely prospected or mapped geologically. In another section some six important papers dealt with the physiological and psychological effects of heat and humidity on workers in deep mines and in metallurgical works. Four papers were read on present-day trends in mineral dressing, while some twelve papers dealt with aspects of metallurgy and the metallurgical industries. Only three papers were devoted to coal and coal mining; one on the coal resources of the British Commonwealth, another on the characteristics of Empire coals and their bearing on the industrial potential of the Empire, and a third on modern trends in coal mining practice in Great Britain.

Petroleum Resources

The Commonwealth and Empire produce only some 2 per cent of the world's petroleum supply, and therefore it is perhaps not surprising that the subject of petroleum did not figure prominently in the proceedings of the Congress. A short time ago it seemed

probable that Professor Illing would read a paper on the petroleum resources of the Empire, but unfortunately this did not prove to be possible. However, Mr H. W. Lane presented a valuable paper on modern drilling and production practice in the oilfields of South Iran. The paper dealt with the standard drilling programme and mud technique; with pressure drilling, which has enabled high pressure conditions in the upper formations to be overcome; and included a description of drilling through the reservoir rock. The section dealing with production explained the principles of unit control, stress being laid on the importance of collecting accurate reservoir data. The paper also described the surface production system, and included a reference to the unique practice of recycling the surplus products of refining. The paper contains many illustrations, including photographs of the oilfields and cross-sections showing the underground structure of the most important fields.

Dr Taverne read an interesting paper on the application of auger and core drilling in petroleum exploration. He explained the methods of shallow and deep hand augering, the various methods of core drilling, oriented percussion drilling, and deep core drilling. He showed that auger drilling can yield useful evidence, particularly in dense jungle areas of tropical countries where outcrop evidence is scarce or obscure, and where the solid geology is hidden beneath soil or a thin cover of drift or alluvium. Auger drilling is supplemented by the taking of oriented percussion cores. Core drilling is undertaken to check geophysical results in alluvial areas, to obtain precise information respecting concealed thrusts and faults, and also to obtain stratigraphical and structural evidence beneath a thick cover of alluvium or an unconformable series.

There were references to petroleum in other papers. Sir Lewis Fermor referred to the remarkable development of the Seria oilfield in Brunei State, and the paper by E. H. Beard contained an account of the petroleum industry of Trinidad. Another paper dealt with aerial photography in petroleum and mineral prospecting, while the paper by C. J. Sullivan on mineral exploration in Australia contained a small section devoted to petroleum technology.

In addition to the technical papers dealing with petroleum, there was an important exhibition of oilfield development, which was sponsored by the petroleum industry in Great Britain. (*I.P.Review*, Sept. 1949, p. 273.)

The technical sessions were followed by excursions to Cardiff, Cornwall, Edinburgh, and Newcastle-upon-Tyne. Visits were paid to several collieries and iron-ore mines in South Wales; also to several important steelworks and to National Oil Refineries Ltd. at Llandarcy. The excursion to Cornwall included visits to tin mines, and a whole-day tour of the china clay district. The trip to Edinburgh included visits to shipbuilding works, collieries and factories, and to the Philpstoun oil-shale mine and the Westwood crude oil works. The excursion to Newcastle-upon-Tyne enabled members to visit the big shipyards.

The Congress was highly successful, and members from all parts of the Commonwealth and Empire will long retain most pleasant memories of their sojourn in the mother country during the wonderful summer of 1949.

During the Congress an invitation from Australia and New Zealand to hold the Fifth Empire Mining and Metallurgical Congress in Australasia in 1953, was received with much pleasure and accepted with thanks by the Empire Council of Mining and Metallurgical Institutions.

OUR CREST

Immediately after the war the urge was "Research", and in conformity with this trend a north-western petroleum refinery erected an architect-designed research and development laboratory. On completion there was a gap over the entrance doorway, which was finally filled by a sculptured plaque with main motif a bird, with wings outstretched, grasping a glass retort.

The design was pleasing and would probably have remained of passing interest for its artistic qualities alone had not the research laboratory immediately become known to all employees as "The Duck and Bottle". The "bottle" or the glass retort has always been the recognized symbol for laboratory work. The "duck" was an unknown quantity.

On consultation with the sculptor responsible for the design it transpired that he had carried out a considerable amount of investigation to obtain a symbol which would be representative of the petroleum industry. Being unconnected with the industry, his scan was wider than would otherwise have been the case. His final decision was that the requirement was met by the *Archaeopteryx*. The employees' "duck" was, in fact, a sculptured rendering of the *Archaeopteryx*.

The name conveyed little even to those erudite in such questions. It is, however, fully covered in the literature from which the following salient information is extracted. The *Archaeopteryx* is of historical interest in that it represents the evolutionary stage between the reptile and the bird. Such information as is now available on its living appearance has been built up from a few skeletons recovered from the Jurassic limestone in Bavaria, Germany.

Petroleum literature discloses the fact that as early as A.D. 1436 petroleum was derived from the Tegernsee district of Bavaria and that the oil is said to come chiefly from limestones and sandstones of Upper Jurassic age.

Let us say straight away that there is no direct connexion between the *Archaeopteryx* and petroleum. The petroleum in Bavaria did not derive from *Archaeopteryxes* nor is there reference in the literature to the skeletons being found in oil-bearing strata. There is, however, certain evidence that the geological age of the skeleton strata is similar to that of the oil-bearing formation.

Drake's well, typical of the period, is generally regarded as being symbolical of the birth of the petroleum industry, as we know it now. The *Archaeopteryx*,

typical of the period, is symbolical of the birth of petroleum.

Whether or not the sculptor was questing for a symbol for petroleum or for the petroleum industry, it was a happy chance that he made available the *Archaeopteryx* to a scientific body interested in petroleum. It is as such that we would regard the *Archaeopteryx*, but a further peculiar chance might be noted. The *Archaeopteryx* was the flying stage in the evolution of reptile to bird. For long the bird was an inspiration to man, who finally achieved flight by evolving wings of petroleum. So much for the symbol and its history. Now for a short history of the evolution of our Crest.

At the request of a Council member the sculptor sketched a Crest utilizing the *Archaeopteryx* as main motif. This was of artistic excellence, but at that period the significance of the *Archaeopteryx* was not fully realized. Council members tended to favour the oil derrick but without unanimity of opinion.

Recommendation was made, and Council agreed that the Crest question be referred to the College of Heralds, which action would have the added advantage of resulting in an officially registered design.

The first design submitted by the College of Heralds was based on the oil derrick. It was apparent from this that the oil derrick was unsuitable as a main motif for crest purposes.

The College of Heralds suggested that they could work out a satisfactory design if the *Archaeopteryx* was utilized as main motif. The utilization of the *Archaeopteryx* for this purpose was agreed by Council. The suggestion of a Council member that the Institute's motto *Conjunctione potiores* be included in the Crest was also accepted.

Working to these guiding features the College of Heralds evolved and submitted a design. One anticipates a certain diversity of opinion on artistic work. In this respect the submitted design was unique. It met with immediate unanimous approval by the committee responsible and by Council members on its submission to Council by the committee.

In a previous article our monogram was described. The monogram proper covers our Institute as a scientific body. The circular surround provides the connecting link of our Institute with the petroleum industry. The symbolism utilized stresses the unity of operations within that industry.

Let us be candid and state that by chance and not by design our crest exactly parallels our monogram. The crest covers our Institute as a scientific body interested in petroleum. The motto, which may be literally translated "Strength through unity", provides the connecting link with the petroleum industry. The basic thought of unity is exactly similar.

But for the questing mind of a sculptor the history of our crest might have been less facile. To Mr Geo. T. Capstick of Liverpool we tender our acknowledgement and thanks.

(The Institute is indebted to Mr J. S. Parker, not only for the above contribution, but also for the great amount of work he has performed in connexion with the Institute's new crest.—Editor.)

PREPRINTS

Due to the ever-increasing costs of printing and the large demand for preprints of papers to be read before the Institute, it has been found necessary to make a small charge for these. Consequently, the preprints of the paper or papers to be read at a meeting will be 1*s.* post free. Those wishing to receive preprints of all papers during the session can do so at a cost of 5*s.* post free.

SIGNIFICANCE OF PROPERTIES OF PETROLEUM PRODUCTS

IV. VISCOSITY, VISCOSITY INDEX, AND RHEOLOGY

By ALFRED H. NISSAN (Fellow)

VISCOSITY

Simply, viscosity is a measure of the resistance met when two layers of a liquid are made to slip past each other. Newton termed it the "deficiency of slipperiness" shown by liquids and gases. There are many ways of noting this property. For example, when two vessels, one containing petrol and the other a lubricating oil, are stirred, two differences appear immediately.

(*i*) *Much less effort is required to stir the petrol than the oil.*

(*ii*) *The petrol shows turbulence, vortices, and generally chaotic criss-crossing of the streams more readily than the lubricant, which tends to flow along more orderly and smoother lines—the so-called "streamlines".*

Both of these differences are due to the fact that the oil is more viscous than the petrol, and they constitute the two main interests which the petroleum technologist has in viscosity. The first observation, that the more viscous an oil is, the greater the effort required to make it flow, is of direct and obvious importance. For example, in the flow of petroleum products in underground reservoirs, up the well, or along pipelines either to refine or to transport it from one place to another—in all these flow processes expenditure of energy and, consequently, of money, is required to overcome the effects of viscosity. In other respects this need for large forces to overcome viscous resistance is utilized effectively; for instance, in the lubrication of bearings, the higher the viscosity of an oil the greater will be the maximum load allowable on the bearing when other factors are equal.

The second observation, that viscous oils tend to flow along orderly streamlines, constitutes the second main interest of the petroleum engineer in viscosity, but in a more subtle way than the first, and perhaps requires a short explanation.

As mentioned above, liquids can be observed to flow either in smooth parallel layers or in turbulent chaotic ever-changing patterns. The same liquid can be made to flow in either way. By increasing the speed of flow or the density of the material, turbulence is induced; by increasing the viscosity the so-called "streamline régime" is stabilized. The important point is that the same liquid in the same container has certain very markedly different characteristics in the two régimes. It will, for instance, have a very much higher heat transfer coefficient when turbulent than when it is in streamline flow. Again, when a jet of liquid is ejected from a nozzle its tendency to break up into drops is much greater if it is turbulent than if laminar. Even the pressures necessary to move it in a pipeline are very much dependent on what régime is obtaining in the pipe. Doubling the speed of flow in the streamline régime requires doubling the pressure. In fully turbulent régimes, doubling the speed requires four times the pressures. These differences do not exhaust the list, but illustrate how important they are in the practical field.

Thus the petroleum engineer is interested in the régime of flow obtaining in his system, because the régime determines for him a host of important characteristics of the oil which are of direct influence on the design and operation of his plant. The influence of

viscosity on the type of régime that can be maintained is so great that flow in the streamline or laminar régime is also called "viscous flow".

The viscosity of an oil is affected by several factors. The molecular constitution of the oil is obviously of fundamental importance. Thus aromatics are more viscous than paraffins of equal molecular weights. As viscosity is a measure of the interaction of layers of a liquid resisting their slipping over each other, it follows that any chemical factor which affects the constituent molecules of the liquid will have some effect on its viscosity. However, physical conditions have their effects too and, of such conditions, probably the most significant is temperature. Pressure generally increases the viscosity; probably the influence of the very high pressures that sometimes obtain in bearings has not been given its due importance in the past, but there is evidence of greater awareness of this influence in recent work. Nevertheless, it is safe to state that the effects of temperature are by far the most important in the majority of viscosity problems in the petroleum industry.

A rise in temperature will always result in a marked drop in the viscosity of petroleum products which have not been specifically "doped" to modify this effect. For oils of high viscosity a rise of only 20° F is sufficient to halve the viscosity. The greater the viscosity the greater is the effect of temperature changes upon it. Thus, less viscous oils will generally show a smaller percentage change of viscosity than more viscous oils for the same temperature change. This rule applies to a single oil too as it is progressively heated. The drop in viscosity, consequent on heating an oil from 0° F to 10° F (when its viscosity is high), is severalfold greater than when heating the same oil from 200° F to 210° F. Thus, the curve shown in Fig. 1 is very general and applies qualitatively to most oils when compared with each other, and also for one oil at different temperatures.

Viscosity Index

The change of viscosity with temperature being one of the most important properties of an oil, it would be most useful if the viscosity temperature characteristic of all oils could be represented

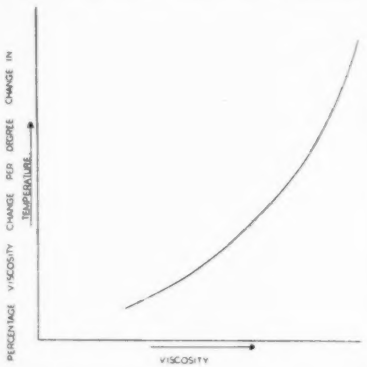


Fig. 1.—The relationship of percentage viscosity change due to a change in temperature with viscosity.

accurately by a single curve as in Fig. 1. Oils, however, whilst obeying this rule generally, show important differences in detail. These relatively small differences are of paramount importance in practice. To illustrate both the general similarity and the small but important differences in detail, two oils may be studied.

Oils *A* and *B* are chosen so that *A* represents a class of oils which have a very good viscosity stability with temperature compared with oil *B*, chosen from a class which is very poor from this viewpoint. The oils are of nearly the same viscosity at 100° F, namely, 1921 and 1922 centistokes (cs) respectively. When these two oils are heated to 210° F oil *A* drops in viscosity by 1846 cs or 96 per cent, whilst oil *B* drops by 1882 cs or 98 per cent. Thus, in general, the percentage drop in viscosity of the

extremely different oils is 97 ± 1 per cent. Nevertheless, in practice their difference is of marked importance: oil *A* with a viscosity of 75 cs is nearly twice as viscous at 210° F as oil *B* with its 40 cs, although they both have the same viscosity at 100° F.

This example points to several matters of importance to the oil engineer. It illustrates numerically the very great change in the viscosity of oils when they are heated. Thus the problem of lubricating an internal combustion engine with the same oil, both when starting cold and when running at the optimum temperature (involving a change of over 150° F), immediately necessitates a close study and control of the viscosity-temperature characteristics of the oils to be used. As Fig. 1 shows that the change of viscosity with temperature depends on the viscosity value itself, it becomes necessary to specify the viscosity at which the two oils are to be compared, at least at one temperature. Otherwise a viscosity-stable oil of high viscosity will always compare unfavourably even with a viscosity-unstable oil of low viscosity if merely the change of viscosity on testing is reported either in absolute values or as a percentage.

Further, it illustrates the need for a fine scale in characterizing the oil: when the oil is heated from 100° F to 210° F a difference of 2 per cent of the viscosity at 100° F means nearly 100 per cent difference in the viscosity of the oil at 210° F. Therefore, having specified the viscosity of an oil at one temperature, it is necessary to specify most accurately the viscosity drop of the oil. Instead of specifying the viscosity drop as a percentage carried to three or four significant figures, it is simpler to specify the actual viscosity at some higher temperature. Thus it should be fairly rigid if, say, the viscosity of the oil were specified at two convenient standard temperatures to represent low and high values, say, 100° F and 210° F. Oils could then be compared on an equitable basis for viscosity-temperature stability. The trouble with such a system is that it is too rigid; for example, oils could not be specified in types or classes but only individually.

Dean and Davis solved this problem in the following manner. They examined two series of oils, one representing a stable and the other an unstable viscosity-temperature character. They called the first series the *H* series and the second the *L* series. They determined the viscosities of the oils in both series at 100° F and 210° F, plotted their results, and generally smoothed out irregularities. Thus they had a number of values for viscosities of oils at 100° F and 210° F. To illustrate, the *H* series had the following smoothed values for some of its oils:

Viscosity at 100° F	30·040	89·178	1010·4	1921·3
Viscosity at 210° F	5·00	10·00	50·00	75·0

The *L* series, similarly, had the following corresponding values:

Viscosity at 100° F	42·570	162·494	2990	6446·7
Viscosity at 210° F	5·00	10·00	50·00	75·0

(Oils of intermediate values are also listed, but these two tables illustrate the general trend.) Then they considered an oil of unknown characteristic. They measured its viscosity at 210° F and found, say, it was 10·00 cs. If the viscosity of the oil at 100° F was 89·178 it would be equivalent to the *H* series of high viscosity-temperature stability and could be called an *H*-oil. If, on the other hand, it was found to be 162·494, then it could be equivalent to the *L* series, of low viscosity-temperature stability and called *L*-oil. However, in practice, very rarely was an oil exactly like the one or

the other; generally the viscosity at 100° F for an oil of 10·00 cs at 210° F was higher than the 89 cs of the *H* series, but lower than the 162 cs of the *L* series. It might be found to have, say, 130·0 cs at 100° F. Therefore, they determined the difference between the *L* series oil at 100° F and the unknown oil and also the difference between the *L* and *H* oils at 100° F i.e., $(162{\cdot}494 - 130{\cdot}0) = 32{\cdot}494$ and $(162{\cdot}494 - 89{\cdot}178) = 73{\cdot}316$.

The unknown oil was deemed to be as far above the *L* series in its viscosity-temperature quality compared to the *H* series as 32·494 is to 73·316. Calling the level of *H* series in relation to the *L* series 100, then the unknown oil will be rated as $\frac{32{\cdot}494}{73{\cdot}316} \times 100 = 44{\cdot}3$ or, say, 44. They called this rating the "viscosity index" or the V.I. of the oil.

Thus, to recapitulate, the viscosity index of an oil denotes how it compares with two hypothetical oils having the same viscosity as itself at 210° F, but different viscosities at 100° F. Tables and nomographs exist for the rapid calculation of the V.I. from the two viscosities at 100° F and 210° F. The two oils *A* and *B*, quoted above as having nearly the same viscosity at 100° F, have 100 and 0 viscosity indices respectively.

The V.I. has been the subject of criticism and other systems have been proposed. It is, nevertheless, accepted as a standard method of comparing oils for their viscosity-temperature relationships in both Britain and the U.S.A. and in several other countries.

Viscosity Measurements

To control or specify the viscosity and viscosity-index of oil, it is necessary to develop some technique and apparatus for measuring this property. There are very many ways of measuring viscosity, but all fall into one of two main classes. The first class comprises the absolute methods whereby from measurements of the dimensions of the apparatus, of the pressures or forces involved and of the speeds of motion, the viscosity is calculated by means of equations developed in the science of hydrodynamics. The second class utilizes the results of the first in the following manner: at very low speeds the resistance put up by liquids against flow is generally proportional to the viscosity of the liquid. Thus, if two liquids are made to flow through the same tubes under very carefully standardized conditions, a given quantity of the more viscous liquid will take proportionately longer time to flow through the apparatus than the same quantity of a less viscous liquid. If the viscosity of one of the two liquids is known from absolute measurements the viscosity of the second is obtained from the ratio of the times.

Practically all the standard methods belong to the second class and use a narrow tube at the bottom of a reservoir as the main parts of the apparatus. A specified quantity, usually automatically measured by marks on the reservoir or by similar devices, is timed as it flows through the tube under automatically controlled pressures or heads of fluid. The basic standard is water; substandards are calibrated against water and are in turn used to calibrate the instrument so that 1 second of time of flow signifies a certain number of units of viscosity. The greater the accuracy required from the apparatus, the longer and narrower will be the tube; the closer the tolerances on the dimensions and the more precise is the control of the driving head and of the temperature of the fluid. The most precise and accurate viscometers are usually made of glass, well surrounded by thermostatically controlled baths. The least precise and accurate are metallic cups with short holes at the bottom and with loose control of temperature, driving heads, and quantities flowing. In practice, the choice of apparatus will entirely depend on what is required from the information obtained about the viscosity. For

example, it has already been implied that for V.I. determinations only the most accurate standard methods are really suitable. However, for a very large number of control tests and for approximate evaluation of the viscosity the simple cup-and-hole viscometers may be found suitable. In general, however, there is a movement away from the rough-and-ready cup viscometers to the glass U-tube viscometers of the Institute of Petroleum, the British Standards Institution, or of similar bodies in the United States and other countries.

Fig. 2 illustrates a standard all-glass U-tube viscometer used for measuring the viscosity of oils in absolute units, i.e., in centistokes (cs). This type of apparatus is specified by the B.S.I. and the Institute of Petroleum. The dimensions of the bulbs and tubes are closely specified. However, as two tubes made to the same dimensional specifications can still give measurable differences in viscosity values on the same oil, the procedure is to calibrate the tubes with water or with oils, the viscosity of which is already known.

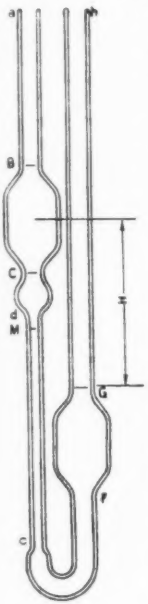


Fig. 2.— U-Tube viscometer.

The method of calibration and use is as follows: after cleaning and drying the tube, it is filled with the liquid under test up to mark *G* and suspended in a bath so that it is vertical. The liquid is allowed to come to the temperature of the bath, which is maintained constant to a high degree of accuracy. If necessary, the level of the oil is brought back to the mark *G* after the temperature of the liquid is stabilized. To determine the viscosity the oil is sucked up into bulb *BC* so that its upper level is a little above *B* and allowed to flow freely to its original position. The time taken for the upper level to fall from *B* to *C* is noted with an accurate stop-watch. This time is very nearly proportional to the viscosity of the liquid. Thus, by using a liquid of known viscosity the proportionality constant can be determined and used to convert times of flow of other liquids into viscosity units in centistokes.

The time of flow is proportional to the viscosity only if it exceeds a certain minimum value of the order of a few hundred seconds. For shorter times of flow, corrections can be determined and applied. To ensure reasonably long times of flow with non-viscous liquids like kerosine, say, the tube *Me* is made of a narrow bore capillary. For more viscous lubricating oils, such narrow capillaries would yield far too long times of flow for convenience—e.g., several thousand seconds. Therefore, a set of viscometers is specified with progressively larger capillary diameters to be used with different oils so that for each viscosity value some tube will be found which will give a time of flow between, say, 200 and 1000 seconds. Thus, there are five U-tube viscometers of this type specified which will give approximately the following values for viscosity for a time of flow of 500 seconds:

Tube No.	0	1	2	3	4
Approximate viscosity in cs for a time of flow of 500 sec.	0·25	2·5	25	150	1000

Hence, tubes can be selected to measure the viscosity of such mobile liquids as water and petrol (up to 1 cs), kerosines (2 to 3 cs), light diesel fuels and gas oils (5 to 15 cs), or fairly viscous lubricating oil of, say, the consistency of castor oil (1000 cs) with a reasonably short yet sufficiently accurate time of flow.

The second class of standard viscometer, which is more robust but less accurate than the all-glass U-tube viscometer, may be illustrated by the Redwood viscometer shown in Fig. 3. In this apparatus the oil is placed in the central cup to a fixed level. The short and narrow hole at the bottom of the cup is closed by a ball valve until the temperature of the oil is at the required value. The temperature of the oil is controlled by the temperature of the outer bath. When the conditions are right for a determination, the ball valve is removed from its seat and the oil flows through the agate jet into a standard flask of 50 ml capacity. The time taken for the oil to fill the flask up to a standard mark—i.e., the time for 50 ml of oil to flow through the jet—is noted and reported as the Redwood viscosity in seconds. This time is only approximately proportional to the viscosity. Again, there are two specifications for Redwood viscometry: a Redwood No. I for less viscous oils, and Redwood No. II for the more viscous oils. Therefore, the full report for the viscosity of an oil which took, say, 300 seconds in the No. I instrument at 200° F would read "Viscosity, Redwood No. I at 200° F, 300 sec".

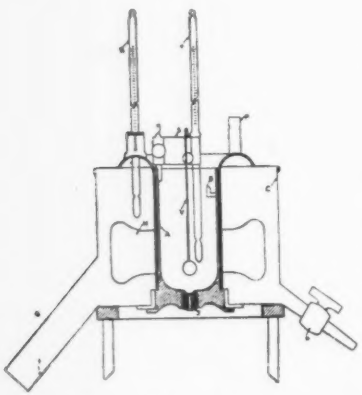


Fig. 3.—Redwood viscometer.

The Redwood viscosity in seconds is only approximately proportional to the absolute viscosity in centistokes. Nevertheless, tables have been compiled which can be used to convert one system of viscometry into another. The Institute of Petroleum publishes such a table as an appendix to its handbook on "Standard Methods". The conversion factors depend, to a small extent, on the temperature of measurement, but, as a guide, the following figures illustrate the order of magnitude in converting one system to the other:

Viscosity in cs	5	10	50	100
Viscosity, Redwood No. I at 140° F sec.	38·5	52·0	204·7	408·2

For viscosities above 100 cs the figure in centistokes may be multiplied by 4·1 to give an approximate value of the Redwood No. I viscosity. Redwood No. II viscosities in seconds are always one-tenth the values of Redwood No. I, e.g., an oil of Redwood No. I viscosity of 500 seconds will give Redwood No. II viscosity of 50 seconds at the same temperature.

Whilst conversion from centistokes to Redwood seconds may be performed in this manner, Redwood viscometers should not be used for measuring viscosities in cs for accurate work—say, V.I calculations—as they are not sufficiently accurate or precise.

Rheology

In measuring viscosity, the need for very careful control of the temperature is already apparent from what has been stated before. There are other factors to be considered, however. The viscosity of an oil will be affected by the pressure exerted on the oil to some extent; but this can be neglected generally. An important factor is the presence of other substances in the oil. Accidental impurities will have small effects, but "large" quantities of such a substance as a soap

changes the viscosity not only numerically to a higher value but also fundamentally in other respects. The viscosity of the original oil will be found the same at, say, a rate of flow in a pipe of 0·1 ft/sec, as at a rate of 1 ft/sec. When soaps, rubber, or other colloids are present in appreciable quantities it is found that the viscosity at 0·1 ft/sec is very much higher than at, say, 1 ft/sec in the same apparatus. In other words, as the fluid is sheared at a higher rate the viscosity is found to "break down" to a lower value. Again, with an oil the viscosity measured immediately after stirring the oil is found to be the same as that after allowing the oil to "rest" for a considerable time. With colloidal dispersions the viscosity immediately after stirring is generally different (usually lower) than the viscosity of the dispersion after rest; as the dispersion is left quiescent there is a "build-up" of viscosity. Furthermore, an oil will show the same viscosity when heated to moderately high temperatures and cooled to the original temperature, whilst a colloidal dispersion of wax or soap in oil will generally show a different viscosity at the same temperature before and after heating. Finally, an oil will generally show no elasticity—i.e., it cannot sustain a pressure differential without flowing. A colloidal dispersion will sometimes have the ability of storing small or large amounts of mechanical energy without flow. On removing the pressure differential the dispersion will return to its original position or at least will partially retrace its path towards its original position. In all these examples the "viscosity" obtained by a standard viscometer will be of no great value as it is purely the result of fortuitous combinations of several factors.

It is seen that the subject of viscosity is only a portion of a larger subject of the general deformation of matter where elasticity, hardening, and other complicating phenomena appear. This larger science is called "rheology—the knowledge of flow". It is not intended even to summarize here the many complexities of the subject, but it is mentioned to emphasize two general rules: whenever the viscosity of a liquid is found to be sensitive to: (*a*) the dimensions of the apparatus; (*b*) the mechanical history of the liquid, e.g., stirring or shaking; (*c*) thermal history of the liquid, e.g., heating and cooling over a short range of temperature; or (*d*) the rate of motion of the liquid in the apparatus, it is then pertinent to remember that most probably the liquid is rheologically complex. With all such complex liquids the two rules are:

(*i*) *No standard apparatus is really suitable for use to measure all the rheological characteristics of such liquids. Methods falling in the first class, i.e., absolute methods, have to be used with appropriate safeguards and adaptations to the needs of the particular liquid.*

(*ii*) *If the problem is really important, then a specialist in rheology should be consulted. He may not be able to supply the correct answer, but he will most probably avoid the wrong ones and will go some way towards the correct answer.*

Suggestions for Further Reading

Aside from the I.P. "Standard Methods for Testing Petroleum and its Products" and the A.S.T.M. Committee D-2 "Standards on Petroleum Products and Lubricants", which describe, among other matters, the various standard methods available for measuring the viscosities of petroleum products, the appended list should be found useful. The article by Beale and Docksey in the *Science of Petroleum* illustrates the significance of viscosity in flow problems. Barr's book is a classic on viscometry; unfortunately, it is out of print and is becoming difficult to obtain. Scott Blair's book should give a thorough understanding of rheology and is one of the best guides to the literature on the subject. The short article by Hardiman

and Nissan and the discussion following it gives the historical development of the V.I. system, a criticism of its main failings, and an attempt to rationalize it.

1. Beale, E. S. L. and Docksey, P.: "The laws of fluid flow in pipelines", *Science of Petroleum*, Oxford University Press (1938), 718.

2. Barr, G.: *A Monograph on Viscometry*, Oxford University Press (1931).

3. Scott Blair, G. W.: *A Survey of General and Applied Rheology*, Sir Isaac Pitman and Sons Ltd., 2nd Ed. (1949).

4. Hardiman, E. W. and Nissan, A. H.: "A rational basis for the viscosity index system", *J. Inst. Petrol.*, 1945, **31**, 266, and Tadayan, J., Hardiman, E. W., and Nissan, A. H., *ibid.* 1949, **35**, 28.

TRINIDAD PETROLEUM IN 1948

Reporting on the petroleum industry in Trinidad during 1948,* the Petroleum Technologist, W. N. Foster, states that at least four drilling rigs will be in continuous operation on exploratory work for the next two years. No exploratory drilling in deep water marine areas is expected before 1952, but a few locations near shore from existing fields may be drilled during 1950.

Production and Drilling

Total production for the year was 20,107,000 barrels (20,433,000 in 1947) of crude oil, and 182,163 barrels (181,000 in 1947) of natural gasoline.

During the year 22 drilling rigs were in continuous operation, a total of 638,681 feet was drilled, and 134 wells were completed as producers.

The average number of wells producing during the year was 2013, of which 629 were flowing wells, the remainder being produced by artificial lift.

Average daily production per well was 27·3 brl (30 brl in 1947). The average per flowing well was 50·7 brl/day (54·2 brl in 1947).

Refining

Total crude run to stills in 1948 was 27,074,000 brl (3,829,401 tons), an increase of 7·1 per cent over 1947, entirely due to increases in imported crudes. Refinery outputs were:

	Tons
Aviation spirit:	
100 octane	58,545
Other	20,357
Motor spirit	616,499
White spirit	654
Burning oil	59,354
Vaporizing oil	167,534
Gas and diesel oil	561,193
Fuel oil	2,078,369
Lubricating oil and grease	352
Bitumen	61,098
Other products	17,319

Asphalt

Production of asphalt from the pitch lake amounted to 128,993 tons in 1948, as compared with 87,346 tons in 1947.

Contribution to Revenue

In 1948 the petroleum industry contributed $13,227,663 to the Colony's revenue, 26·6 per cent of the total. In addition $2,381,909 was collected in excise in petroleum products.

* Trinidad and Tobago: *Administration Report of the Petroleum Department, 1948*. Trinidad: Government Printer, 1949. 60 c.

L.P.G. FIRE PROTECTION

New standards for the design, installation, and construction of containers and pertinent equipment for the storage and handling of liquefied petroleum gases have just been issued by the American National Board of Fire Underwriters, 85, John Street, New York 7, N.Y., U.S.A. The first (No. 58) applies to the design, construction, location, installation, and operation of L.P.G. systems, and the second (No. 59) to the handling of these gases at utility gas plants.

PARAFFIN WAX PRODUCTION

By OBSERVER

"A TRIP around a petroleum refinery is often disappointing, for one never sees the raw material or the products—only a mass of pipes and containers through which these materials are said to be passing." So said a petroleum engineer when a visit to a refinery was under discussion. But he had overlooked the manufacture of paraffin wax—one of the most desirable and valuable products from petroleum.

So let us go to the Pumpherston refinery of Scottish Oils Ltd., and pay some attention to the section where wax is made, for it is here that we shall be able to see and actually handle the product during various phases of manufacture.

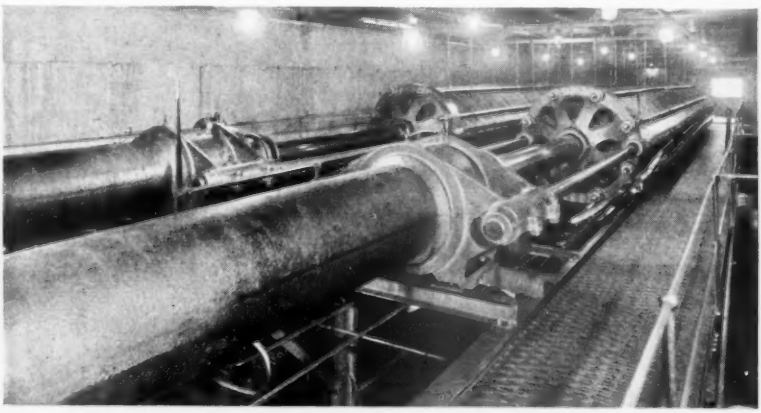
In this refinery crude shale oil from the neighbouring shale mines and crude shale works is first distilled into four primary fractions—crude naphtha, a wax-free cut, a pressable cut, and the residue.

It is the pressable cut in which we are particularly interested, as it is in this distillate, amounting to some 60 per cent of the total crude throughput, that the wax is concentrated. It derives its name from the fact that the main part of the wax recovery process consists of passing this distillate through a filter press.

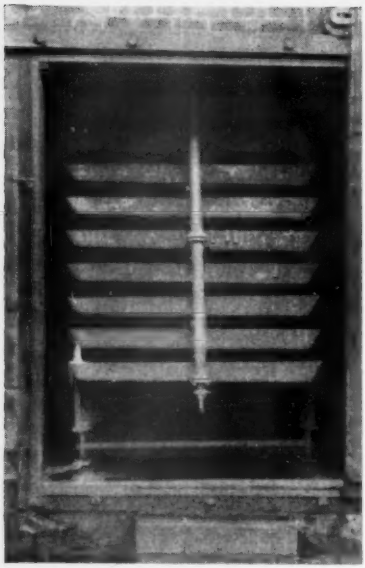
The first treatment of the pressable cut after it leaves the distillation unit is to chill it to a low temperature so that the wax will crystallize. The chilling plant consists of two concentric tubes. The oil to be chilled is pumped through the centre tube, and the chilling medium passes through the annular space between the tubes.

As the wax crystallizes, the mixture of oil and wax tends to adhere to the internal surface of the tubes, and is continuously scraped off by rotating scrapers mounted centrally inside the tube.

From the chilling plant the chilled wax distillate passes to the filtration plant. The filter press consists of 500 plates covered with filter cloths, rings



The filter press is closed by hydraulic pressure to a maximum pressure of 500 p.s.i.



A bank of trays in the Henderson sweating stove.

between the plates forming compartments into which the chilled distillate is pumped through openings in the centre of the plates.

The press is closed by hydraulic pressure, and, as filtration proceeds to a maximum pressure of 500 p.s.i. the wax forms cakes in the rings, and we now see the wax-free oil coming out of the press and draining away to storage.

When filtration is complete, the pressure on the press is released and the plates are prised apart to release the wax cakes, which we now see for the first time. The wax at this stage is of a light brownish colour, for it still contains a certain amount of oil, and as it falls out of the press, it is taken away on a conveyor belt, melted, and pumped to the next stage of the process. This consists of treating the melted wax with sulphuric acid and sodium carbonate solution. The treated wax is then sweated to remove the remaining oil and produce a wax to melting-point specification.

It was fortunate that, while most of the sweating is done in 20-ton vertical tube sweaters, some is still performed in the original Henderson sweating stoves, which permit observation of the process. The sweating stoves consist of a number of shallow trays fitted with expanded metal false bottoms. Water is placed in the trays up to the level of the expanded metal, and the wax cake is melted and run on top of the water until the tray is filled. The wax is then allowed to cool, and when it has resolidified, the water is drained away. The stove is then closed and heating commenced. As the wax warms up, the oil is released from entrainment in the wax crystals and drops into the space below the expanded metal and is drained away. During removal of the oil it is fascinating to see the wax gradually losing its colour and becoming whiter. Sweating is stopped at the point when the correct melting-point is reached. Even now the wax still contains some colour, and further refining is required. So, when the sweat is finished, the heat is increased until the wax melts completely, and in the liquid state is pumped to a plant where it is filtered through Floridin, a

The slab casting room.

decolorizing medium, to remove the colour.

After the Floridin treatment, it only remains to cast the finished wax into cakes. At Pumpherston this is simplicity itself. The casting trays are stacked in slightly overlapping tiers so that as the top layer of trays becomes filled, the liquid overflows and fills each succeeding lower layer in turn until all trays are filled.

After the wax in the moulding trays is completely cooled, the slabs—beautifully white in the case of the best grades—are removed and bagged.

So ends the only completely visible petroleum refining process.

BOILER FUEL IN DIESEL ENGINES IN M.S. *AURICULA*

ON August 17, 1949, the 12,250-ton D.W. 12-knot tanker *Auricula*, owned by the Anglo-Saxon Petroleum Co. Ltd., completed three years' service burning a normal grade of boiler fuel in her 4000 I.H.P. 4-stroke cycle single-acting Hawthorn/Werkspoor diesel engines.

During the three years' normal tanker service, in the western hemisphere, the following has been accomplished:

Distance covered between pilot vessels, 217,823 miles.
Average speed between pilot vessels, 12·04 knots.
Time operating at full power, 18,100 hours.
Total revolutions made by main engine, 141,000,000.
Number of ports visited by ship, 75.

During the first year's service much experimenting had to be done, and the engines operated at times under extremely exacting conditions. For instance, the engine was on occasions run for long periods at greatly reduced power in order to determine the alterations required to ensure reliable operation under unusual conditions occasionally encountered at sea, and to ascertain the effect upon combustion of varying the supercharge air pressure and other factors which could be expected to have an adverse effect upon vital parts.

For a portion of the first year the engine operated on diesel fuel when entering and leaving port, but during the past two years fuel having a viscosity of between 1200 and 1500 sec Red. I at 100° F has been used exclusively. During the three years 9099 tons of fuel have been consumed by the main engine.

The cost of diesel fuel and high viscosity fuel was 83*s* and 61*s* per ton respectively when the *Auricula* was commissioned, and the present-day prices are 98*s* 6*d* for diesel fuel and 47*s* 4*d* for the fuel the engine is now using. On the basis of the prices now ruling at Curaçao and the daily consumption at sea during the past three years, the saving effected in the fuel bill of the *Auricula* by operating on high viscosity fuel is £7734 per annum.

The *Auricula* has lifted bunkers mostly at Mexican Gulf ports, but the eight other Anglo-Saxon tankers of similar size and power so far equipped to operate on high viscosity fuels are trading world-wide and lifting bunkers of Middle East and Far East, as well as Venezuelan origin.

The whole of the high viscosity fuel used on the *Auricula* was purified in accordance with the recommendations made,* and the amount of solid matter extracted per ton of fuel treated has varied from 23 lb to 10 oz in the case of the purifier, and 160 oz to 2 oz in the case of the clarifier, depending upon the source of supply.

The cylinder liners have been gauged

* "The burning of boiler fuels in diesel engines," John Lamb, *Trans. Inst. Mar. Eng.*, 1948, 60, 1–25.

regularly for wear and the average maximum wear until May 1949 was 0·0038 inch per 1000 full power operating hours. Fuel injection and exhaust valves operate for 1500 hours before being removed for inspection.

On no occasion has the ship been delayed in port for engine-room requirements, and the stoppages at sea which can be attributed to the burning of high viscosity fuel total 6½ hours only. Not once has the engine failed to answer telegraph orders from the bridge.

No major difficulties have been encountered, but the high sulphur content of the fuels used, namely, 2½ to 3 per cent, has had an adverse effect upon certain parts. For instance, the piston cooling water telescopic pipe packing normally used when burning diesel fuel is unsuitable for sulphur-containing high viscosity fuels. It has also been necessary to give attention to the piston rod oil scraper packing situated at the top of the crankcase in order to avoid acid-containing substances from entering the crankcase and contaminating the lubricating oil. Good progress towards the elimination of these minor difficulties has already been made, but it will not be until the next paper on this subject is read before the Institute of Marine Engineers in April next that full particulars can be given.

As now adjusted, the *Auricula*'s engine is capable of burning fuels ranging in viscosity from 40 to 1500 sec Red. I at 100° F, but for fuels ranging between 1500 and 3500 sec a different type of fuel injection valve nozzle is required.

During the past twelve months, experiments in the burning of fuels having a limiting viscosity of 3500 sec Red. I at 100° F have been carried out on the test engine at Hawthorn Leslie's, St Peter's works, and the results obtained justify the decision to operate the main engines of the *Auricula* on this grade of fuel when next she puts to sea—JOHN LAMB

"PETROLEUM TECHNOLOGY IN 1946"

JUST issued is Vol. 8 of the Institute's publication *Reviews of Petroleum Technology*. This volume covers the year 1946 and summarizes progress in that year in all branches of the petroleum industry.

In addition, certain subjects which were not included in the previous volume (1941–5) are discussed, such as Regional developments; Transport, storage, and distribution; Oil measurement; Crude oils; Lubricants and lubrication; Insulating oils; Engines and automotive equipment; Economic developments in the petroleum industry; U.K. petroleum legislation.

Throughout its 445 pages there are over 3000 references to the literature. Thus, this book is a mine of information on the petroleum industry developments in the year or years reviewed, and is one which every member of the industry needs to have available.

Price is 27*s.* 6*d.* post free (22*s.* 6*d.* to members of the Institute for one copy only) and it may be obtained from the Institute's offices.

PLUTO AWARDS

The Royal Commission on Awards to Inventors has recommended that awards totalling £15,100, tax free, be paid in respect of the inventions which made the Pipe Line Under The Ocean project possible. The awards and their recipients are A. C. Hartley, C.B.E., F.Inst.Pet., £9000; B. J. Ellis, F.Inst.Pet., £5000; M. K. Purvis, £850; A. E. Price, £250.

Techne Industrial Viscometer.—A leaflet describing this instrument is available from Techne (Cambridge) Ltd., Duxford, Cambs.

A VISIT TO THE FRENCH GAS FIELDS

DURING the recent congress of the Association Française des Techniciens du Pétrole, a visit was made to the Régie Autonome des Pétroles at Boussens. The visitors, who included Mr E. A. Evans, President of the Institute of Petroleum, were welcomed by the Director-General, M. de Vries, who described the work of the R.A.P. as summarized below.

Gasoline recovery plant at Boussens.

EXPLORATION

At the beginning of 1939 work had commenced on Well No. 1, St Marcet, in which, six months later, gas was found at 160 kg/sq. cm. pressure in Cenomanian breccia. Subseqtuently petroleum was found in the Jurassic dolomite.

New drilling equipment was delayed by world conditions but, despite post-war difficulties, 18 wells had been drilled, 12 of which produced gas. On the other structures 16 deep wells had given indications of gas, but had not been put into commercial production.

On the 240,000 hectares held by the R.A.P., 41 wells have been drilled or are being drilled. Many of the wells exceed 3000 metres in depth, the deepest, at Puymaurin, reaching 4044 metres. The total depth drilled is about 100,000 metres.

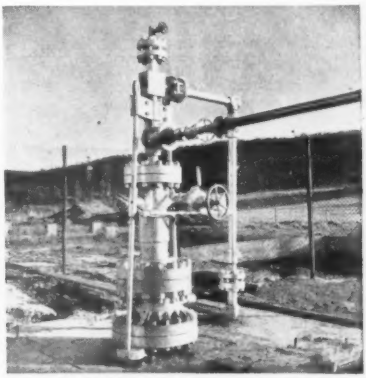
It is hoped to obtain further concessions in Provence, in Savoy, and in the Jura region.

EXPLOITATION

Commercial use of St Marcet gas began in 1942, when a 6-inch pipeline, 85 km long, was laid to Toulouse.

The gas, which consists of 92 per cent

Well No. 1 at Puymaurin.



St Marcet No. 7 has an open flow capacity of 1,500,000 cu. ft./day.

methane and a little nitrogen, contains about 100 g/cu.m. of butane and propane, and is treated at the Peyrouzet works of the Cie Française de Raffinage.

Pipelines totalling 800 km in length serve the towns of Tarbes, Pau, Agen, and Bordeaux, and a second line to Toulouse was completed in 1947.

Current gas production is 700,000 cu.m. per day.

Casing-head Gasoline

The new recovery plant at Boussens can handle 1,200,000 cu.m. (42,000,000 cu.ft.) per day at 70 kg/sq.cm. pressure. At normal capacity output will be 40,000 m. tons of commercial products per annum, and plant is being erected to fill daily 3000 bottles with domestic and industrial gas.

St Marcet

At the St Marcet field, which was visited, there are 12 productive wells linked to a control and water separation plant at the head of the 9½-inch pipeline to the Boussens works. Present pressure is 147 kg/sq.cm.

At the conclusion of the visits, M. de Vries thanked the visitors for their interest in the works, and M. Migaux, President of the A.F.T.P., proposed a hearty vote of thanks to those who had made the visits so interesting.

WORLD OIL MAP

The Petroleum Information Bureau has recently issued a revised edition of its oil map of the world. Measuring 38 by 19 inches, the map shows by coloured squares and circles the location by countries of the world's oilfields and refineries. Main tanker routes are also indicated.

Statistical details of world crude oil production and refining capacity in 1948 are given in tabular form below the map. Copies, price 1*s* each (cash with order), are obtainable from the Bureau, 29 New Bond Street, London, W.1.

ENGINEERING AND MARINE EXHIBITION

Lubrication of industrial machinery and marine and similar diesel engines was the keynote at this year's Engineering and Marine Exhibition, held at Olympia, August 25 to September 10.

Thus the principal exhibit on the stand of **Shell Mex and B.P. Ltd.** was one of the new lubricant testing engines, which has been designed in conjunction with the Institute of Petroleum, and is intended for use in testing for H.D. lubricants. This engine was demonstrated in operation and presented a good insight into methods of collecting research data. Other products of the company and its associates were exhibited.

The stand of the **Anglo-American Oil Co. Ltd.** comprised samples and information concerning industrial lubricants, including such materials as launching greases, etc.

Germ Lubricants Ltd., in addition to samples of various lubricants, demonstrated the Bollard oiliness comparator.

Industrial and marine oils and greases were also exhibited by **Messrs C. C. Wakefield & Co. Ltd., Sternol Ltd., Messrs Alexander Duckham & Co. Ltd., Messrs Albright & Wilson Ltd., Messrs Fletcher Miller Ltd.,** and **Messrs. Edgar Vaughan & Co. Ltd.**

Much plant of interest to the petroleum industry was on view, and there were numerous examples of diesel engines of all types—marine, locomotive, and stationary.

"Puremor" Textile Spray.—Among the exhibits at the Textile Machinery Exhibition which opened in Manchester on October 12 was the "Puremor" textile spray equipment for the preconditioning of cotton and synthetic fibres.

OIL FOR THE FUTURE*

By E. V. MURPHREE

President, Standard Oil Development Company

E. V. Murphree

THE demand for oil products in the United States has increased during the last ten years at a rate of 6·5 per cent per year compounded annually. In 1947 consumption increased rapidly to 5,400,000 brl/day, an increase of about 11 per cent over 1946, and the U.S. was hard put to meet the demands for oil products. In 1948 the rapid rate of increase in consumption of petroleum products started to die off and was only about 6 per cent above 1947. A continued levelling off in consumption is expected in 1949. During 1948, supplies came into balance with demand, and to-day there exists surplus capacity.

Interest has again developed in the production of synthetic fuels from natural gas, coal, or oil shale. A considerable amount of research and development has been carried out since the war in this field by various oil companies and by the U.S. Bureau of Mines.

NATURAL RESERVES

As the first step in determining from where oil for the future may come, it will be helpful to consider the reasonably well-established supplies of crude oil, natural gas, coal, and oil shale, and at the same time to consider supplies of oil and natural gas that may be expected to be found in the future. In the case of oil and natural gas, "*potential supplies*" is the sum of the proven reserves plus possible future discoveries.

Figures are frequently given on the proven reserves of crude oil and natural gas, i.e., known supplies in the ground and not to be confused with the potential supplies. The proven reserves, which show a steady increase, should be regarded as a working inventory from which material is being withdrawn to meet current needs and to which material is being added through both new discoveries and extensions of known fields.

For the purpose of estimating for how long the world's needs of oil products can be supplied from crude oil, proven reserves are of little value. Recognition must be taken of possible future discoveries and for this reason "potential supplies" should be used. How sound the figure used for potential supplies may be depends on how good the estimates are on new discoveries. Oil and natural gas are normally found in sedimentary deposits of marine origin, and an estimate can be made of the volume of such sedimentary basins scattered throughout the world. By applying an estimate of oil yield per unit of volume, an estimate can be obtained of how much undiscovered oil exists in the earth.

The proven oil and distillate reserves for the United States are about 27,000,000,000 barrels, about 12 to 13 years' supply at the 1948 rate of consumption. Proven reserves for the western hemisphere and for the world are about 40,000,000,000 and 78,000,000,000 barrels respectively. The latter figure is the equivalent of about 23 years' supply at the 1948 world oil consumption rate.

For natural gas the proven reserves in the U.S. are about 174,000,000,000,000

* Summary of an address to the Oil Industries' Club, July 5, 1949.

cubic feet, and for the world as a whole about 290,000,000,000,000 cubic feet. At present efficiency for conversion, the United States reserves would be equivalent to about 17,000,000,000 barrels of oil and those of the world to about 29,000,000,000 barrels. In the U.S. the bulk of the natural gas will probably be required for use for fuel as such.

Synthetic Production

The estimates on oil shale and tar sands are based on various geologic surveys and are probably fairly accurate for the U.S. and certain other countries. There are vast areas in the world, however, that have not been explored in detail, and actual figures may well be higher than those to be presented.

Estimates on coal and lignite that are given for the U.S. are based on a study made by the U.S. Geologic Survey in 1907. There is little new basic information and these figures have not been greatly changed. Many people in the coal industry feel they are too high by a magnitude of up to fifteenfold.

Table I gives some estimates on usable reserves of oil shale, tar sands, coal, and lignite.

The potential oil represented by these materials is quite large. The figure for coal in the U.S. may be too high, and allowance should be made for coal required for present use at about 600,000,000 tons per year.

Future crude oil production rates for various areas of the world depend on demand and on how rapidly present fields are produced and new fields found. The western hemisphere could readily be self-sufficient for 15 to 20 years and maybe much longer. Assuming that western hemisphere supplies are readily available to the U.S., it does not appear necessary to create there a synthetic fuels industry at present. Real progress is being made in the U.S., however, in the techniques for producing synthetic fuels, and further advances coupled with possible further increases in the cost of finding and developing crude oil supplies, may well lead to the creation of a synthetic fuels industry on a purely economic basis.

Hydrogenation of coal to produce oil products was practised widely in Germany before the war, and there was one large plant in England. In the U.S. a great deal of experimental work has been carried out on the hydrogenation process, particularly for increasing the yield of light products from crude oil and to making certain special products. At present the Bureau of Mines is building a demonstration coal hydrogenation plant. It does not appear that hydrogenation offers an attractive a means of converting coal into oil products as the Fischer-Tropsch Process.

Fischer-Tropsch Process

This process, applied to either coal or natural gas, consists of converting the coal or natural gas into synthesis gas, a mixture of hydrogen and carbon monoxide, and converting the synthesis gas into oil products.

The most important modifications of the Fischer-Tropsch process that have been made in development work in the U.S. are concerned with the catalyst and its application. In the German process

TABLE I

	United States	*Western Hemisphere*	*World*	*Equivalent Years World Oil Supply 1948 Rate*
Shale and tar sands:				
Oil equivalent—million brl	320,000	1,035,000	—	400
Coal and lignite:				
Total—million tons	3,180,000	3,440,000	6,750,000	—
Oil equivalent—million brl	6,360,000	6,880,000	13,500,000	3900

the catalyst was used in a fixed bed between cooling surfaces to control its temperature. Because of the low rates of heat transfer a great deal of catalyst was required and large cooling surfaces. The equipment was involved and expensive. In the U.S. the fluidized solids technique has greatly simplified and lowered the cost of the equipment. Instead of cobalt, an iron catalyst has been used to give a higher octane number gasoline than present-day premium gasoline.

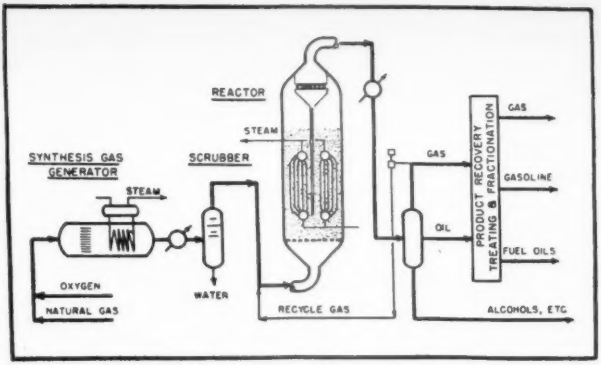


Fig. 1.—The fluid hydrocarbon synthesis process.

The essential features of production of synthetic fuels from natural gas using the fluidized solids technique (Fig. 1) are:

After preheating, the natural gas, together with preheated compressed oxygen, is fed into a synthesis gas generator. The burning zone of the generator is an open chamber lined with refractory insulation, where the methane is converted by partial oxidation to carbon monoxide and hydrogen.

On leaving the combustion zone the hot products of combustion are cooled and passed to the base of a fluid-type reactor. Here, in the presence of an iron catalyst, which, in "fluid" state, is in constant and violent motion, it reacts to form synthetic hydrocarbons and water.

The reaction liberates a very large amount of heat, amounting to nearly 2,000,000 B.Th.U. per barrel of oil produced. High rates of heat transfer through cooling tubes immersed in the fluidized catalyst permit the maintenance of uniform temperature throughout the catalyst, and provide high-pressure steam for heat and power throughout the plant.

The synthesis product leaving the fluid bed in vapour form carries with it a small amount of entrained catalyst, which is recovered in a cyclone and returned through a dip pipe to the catalyst bed. The vapours are cooled and condensed, and some of the uncondensed gases are recycled for further processing. The liquid products—high octane gasoline, diesel oil, and chemicals —then undergo normal finishing treatment.

For the conversion of coal to synthetic oil products the major change in Fig. 1 would be to substitute powdered coal and steam for natural gas. The generator, however, may take a somewhat different form.

One commercial unit for the conversion of natural gas into oil products is now being built in the U.S., and it is believed that one or more satisfactory processes for converting coal into synthesis gas will be evolved.

Shale and Tar Sands

A crude oil can be obtained from oil shale or tar sands by heating the material up to a temperature of 800° to 1000° F. The crude oil distilling off needs considerable refining for conversion into

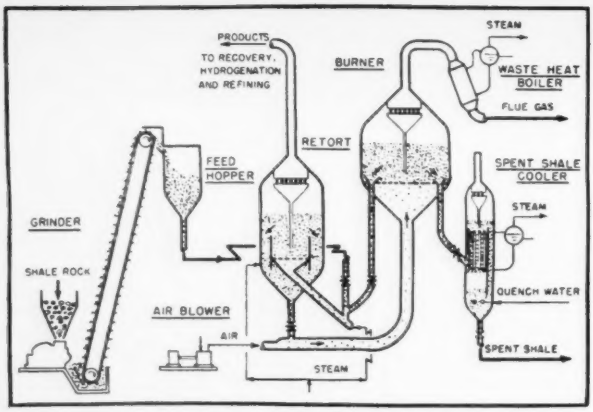


Fig. 2.—The fluid shale-oil retorting process.

satisfactory products, one method being to hydrogenate it and then refine by conventional processes.

For retorting of shale, the fluidized solids technique appears to have application and has been carried out on a pilot plant scale. Other processes are being developed which may have application.

The application of the fluidized solids process to shale retorting is illustrated in Fig. 2. Crushed oil shale is charged to a hopper and then to a retorting vessel containing a fluidized bed of hot previously retorted shale. Contact with the hot, spent shale rapidly heats up the fresh shale, oil products distilling off. In order to keep a supply of hot, spent shale in the retorting vessel, spent shale is withdrawn to a second vessel known as the heating vessel. In this vessel a fluidized bed of spent shale is maintained and residual carbon is partially burned by introducing air into the vessel. The heat of combustion heats the spent shale, which is circulated back to the retorting vessel. Spent shale is discarded as required to keep the proper volume of solids in the vessels. The oil products distilled in the retorting vessel pass on to recovery equipment.

Gasoline Costs

Some estimates (Table II) have been prepared on the investments and costs of making gasoline from crude oil, natural gas, coal, and oil shale. In

TABLE II

Manufacture of 97 Research Octane Number Gasoline

Raw material	*Petroleum*	*Natural Gas*	*Coal*	*Oil Shale*
Location	Gulf Coast	Gulf Coast	East of Mississippi	Colorado
Products market	East Coast	East Coast	Local	Calif.
Total investment per brl/day gasoline	$7300	$8800	$10,900	$9500
Raw material	$2·78/B	10c/MCF	$4·50/Ton	$1·15/Ton
Gasoline cost (cents per U.S. gall):				
Raw material	8·5	2·5	5·5	5·5
Manufacturing and transport	6·0	10·0	16·0	14·0
Total	14·5	12·5	21·5	19·5

considering these figures the following points should be borne in mind:

1. *Investments are for new facilities throughout.*
2. *Estimates are rough and in the case of coal are based on only partly demonstrated processes.*
3. *Estimates are for large plants at particular locations which have been considered favourable locations.*
4. *For petroleum, the posted price for crude oil has been used. This, in general, contains a return on the crude oil production investment.*
5. *Allowance is made for a profit on manufacturing and transportation investment amounting to about 6 per cent on the investment after income taxes. The raw material prices for coal and oil shale are based on roughly the same rate of return on the mining investments involved.*
6. *No allowance has been made for housing that may be required, particularly in the coal and oil shale cases. It is doubted that such housing would be self-supporting. The investments for housing may be quite large.*
7. *97 research octane number gasoline has been selected for this comparison because it is considered to be the grade required by the time that the synthetic plants might be operating.*

The comparison shows that the investment based on crude oil as a raw material is the lowest, the other investments ranging from 20 to 40 per cent higher per unit of gasoline capacity.

It should be realized that there may be more profit in the crude oil production operation than in the natural gas production operation. In the case of all the synthetic fuel processes, technologic advances may be rapid, and equipment designed to-day may soon be obsolete.

In both the natural gas and coal conversion operations chemicals are produced which may find a profitable market. For the estimates it has been assumed that the chemicals would be included to the extent possible in gasoline and the balance thrown away. In the case of coal, it may be desirable first to carry out a carbonization operation to produce tar and fuel gas. The coke so obtained could then be processed to yield synthesis gas. In the figures presented, no carbonization step has been assumed.

It is expected that progress will reduce the investment and cost of producing synthetic fuels.

ELECTION TO COUNCIL

The attention of members of the Institute is directed to the following extracts from the by-laws governing election to the Council of the Institute:

72. Each and every Corporate Member may nominate in writing a Corporate Member for election as a Member of Council. . . . A nomination to be valid must be signed by at least six other Corporate Members and must be received by the Secretary not later than the thirty-first day of December in any year. No member may sign more than one such Nomination Paper at any one election. . . .

Nominations must be made on special forms obtainable from the general secretary.

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FORTHCOMING MEETINGS

INSTITUTE MEETINGS

Synthesis and Properties of Hydrocarbons. Hydrocarbon Synthesis Panel of Research Group. At 26 Portland Place, London, W.1 (tea 5 p.m.), November 9.

Oil Prospects in the Netherlands. W. J. Mulders. At 26 Portland Place, London, W.1 (tea 5 p.m.), December 14.

NORTHERN BRANCH

Greases. C. F. Green. At Engineers' Club, Albert Square, Manchester, 6.30 p.m., November 15.

SCOTTISH BRANCH

The Oilfield Production System Developed in S.W. Iran. H. S. Gibson. At North British Station Hotel, Edinburgh, 7.30 p.m., December 7.

STANLOW BRANCH

ASTM/IP Co-operation in International Standardization with Particular Reference to Oil Measurement. H. Hyams. At Grosvenor Hotel, Chester, 7.15 p.m., November 16.

Operational Research in Industry. R. E. Strong. At Grosvenor Hotel, Chester, 7.15 p.m., December 15.

MEETINGS OF OTHER SOCIETIES

By Sea and Air to South American Oil. J. S. Parker. Royal Institute of Chemistry (London & S. E. Counties Section). At Isleworth County School, 7.0 p.m., November 9; at West Ham Municipal College, 6.30 p.m., November 10.

Submerged Flame Combustion. N. Swindin. Institution of Chemical Engineers. At Geological Society, Burlington House, London, 5.30 p.m., November 22.

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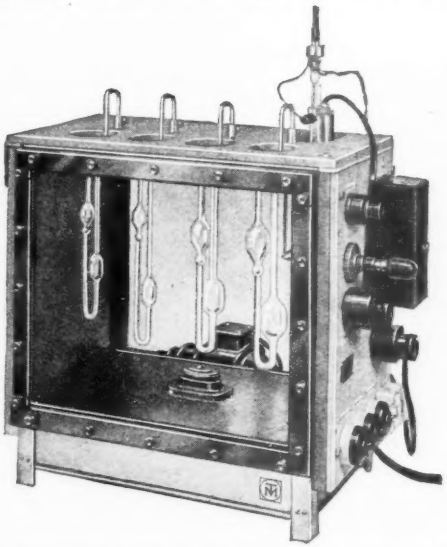

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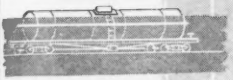

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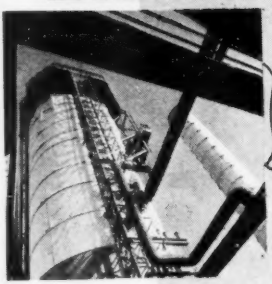

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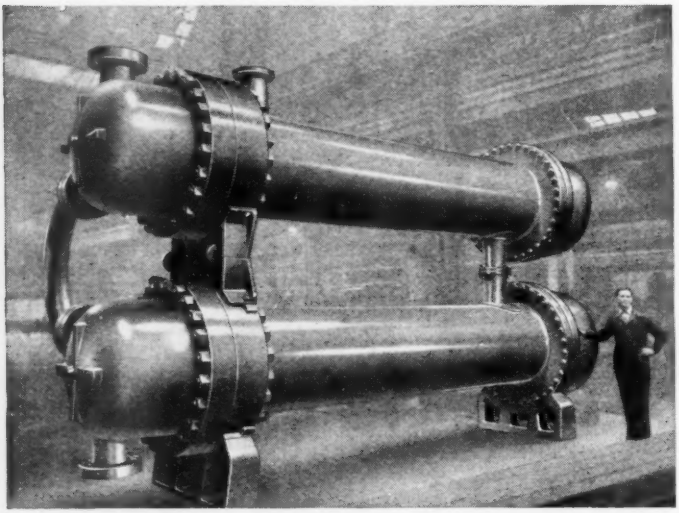

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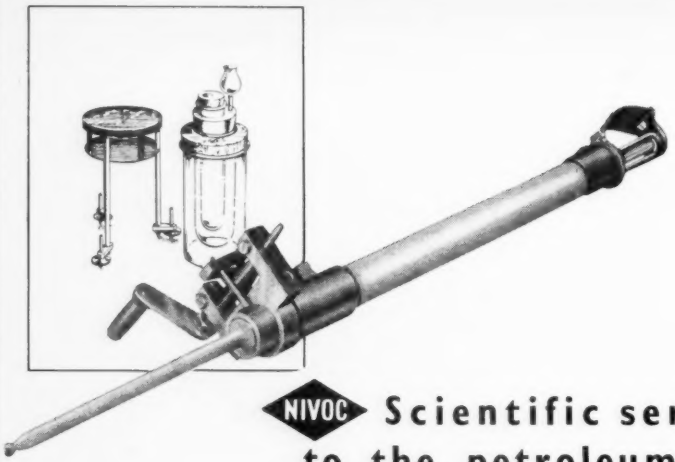

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